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TECHNICAL REPORT ARLCD-TR-81024

DETERMINATION OF MINIMUM NONPROPAGATION DISTANCE FOR 155MM M795 HE PROJECTILES

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APRIL 1981

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LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER TECHNICAL REPORT ARLCD-TR-81024	2. GOVT ACCESSION NO. AD-A099 109	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DETERMINATION OF MINIMUM NONPROPAGATION DISTANCE FOR 155mm M795 HE PROJECTILES		5. TYPE OF REPORT & PERIOD COVERED FINAL May - July 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William M. Stirrat		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS ARRADCOM, LCWSL Energetic Systems Processing Div (DRDAR-LCM) Dover, NJ 07801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MMT-5794288
11. CONTROLLING OFFICE NAME AND ADDRESS ARRADCOM, TSD STINFO Div (DRDAR-TSS) Dover, NJ 07801		12. REPORT DATE APRIL 1981
		13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES This program was accomplished as part of the U.S. Army's Manufacturing Methods and Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel. Test coordination and basic (Continued)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Minimum nonpropagation distance
155mm M795 HE projectiles
TNT
MMT-ammunition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As part of an Army-wide expansion and modernizing program, the safe separation distance for production of 155mm M795 HE projectiles was studied, tested and determined in a series of tests. The test results were used to establish safety criteria for new manufacturing Load-Assemble-Pack (LAP) facilities and also existing facilities under renovation. The program to determine the necessary minimum nonpropagation distance was drafted by ARRADCOM and was subsequently conducted in two separate phases. (Continued)

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18. SUPPLEMENTARY NOTES (Cont)

data reduction were accomplished by the ARRADCOM Resident Operations Office, National Space Technology Laboratories (NSTL) Station, Mississippi. Both exploratory and confirmatory test phases were conducted by the Computer Science Corporation of NSTL.

20. ABSTRACT (Cont)

The exploratory phase consisted of ten separate tests utilizing one donor projectile and two acceptor projectiles. The confirmatory test phase consisted of 25 tests involving 50 acceptors (25 donors), with the spacing distance held constant. Test results indicated that a safe spacing distance of 4.57 meters (15.0 feet) was appropriate.

CONTENTS

INTRODUCTION

Background

At the present time, an Army-wide expansion program is in progress to modernize existing, and develop new manufacturing and Load-Assemble-Pack (LAP) facilities for the handling of energetic materials and their related end items. This systematic effort will enable existing ammunition plants to achieve increased production cost efficiency with improved contingency safety, and also provide for the integrated capability of manufacturing new weaponry within existing facilities. As an integral component of the overall programming concept, the Special Technology Branch, Energetic Systems Process Division, Large Caliber Weapons Systems Laboratory of ARRADCOM, Dover, N.J., under the direction of the U.S. Army Production Base Modernization Agency, is currently engaged in the development of specific safety criteria in direct responsive support of ammunition plant manufacturing and LAP operations.

Objective

The primary objective of this program is to establish and statistically confirm, through experimental evaluation, the safe non-propagative separation distance between 155mm M795 HE Projectiles as they progress from one loading operation to the next along their production line. The development of statistically acceptable safety criteria for use in determining loading line spacing for existing and future ammunition plants utilized in the production of this projectile is also intrinsic to this program.

The overall program effort is to supplement and/or modify existing safety regulations and criteria pertaining to the safe spacing of ammunition and other energetic materials to assist explosive loading plants in their LAP layouts for the most effective and economic man-machine relationship.

Criteria

This test program was implemented to determine the safe spacing of 155mm M795 HE Projectiles under simulated loading plant conditions, so that the effects of a major unscheduled detonation of a munition on the assembly line will be limited to the immediate area and/or loading bay, and not be propagated to either adjacent loading activities or the entire facility causing catastrophic results. Therefore, the only acceptable criteria in

the establishment of safe separation distances is the non-propagation of the donor detonation to the acceptor units.

All safe separation distances specified within this report are measured between axial centerlines of the donor and acceptor units.

TEST CONFIGURATION

General

Testing of the 155mm M795 HE Projectile to establish and statistically confirm the minimum non-propagative distance between donor and acceptor projectiles, under simulated manufacturing line conditions, was conducted at the National Space Technology Laboratories Hazard Range Test Facility in Mississippi. Tests were initiated during May 1980 and were completed during July 1980.

After a facility review meeting, it was determined that the projectile test positioning should be a vertical, base-down configuration with a fully cast-loaded funnel inserted in the nose of each test projectile.

As mentioned, the actual test program consisted of two phases: an exploratory phase and a confirmatory phase. By utilizing various donor-to-acceptor centerline distances during the exploratory phase, the minimum non-propagation distance between adjacent projectiles could be established. The following confirmatory phase consisted of a sufficient number of tests at the previously determined non-propagation distance, to establish a statistical reliability of the non-propagation at that distance.

Test Specimens

The test specimens utilized for this study program were the unfuzed 155mm M795 HE Projectiles, with the lifting plug removed and a fully loaded casting funnel inserted in the projectile nose cavity (fig. 1). The projectiles were always oriented vertically (nose up) at detonation and were only tested singularly.

The 155mm M795 HE Projectile is 74.8 centimeters (29.5 inches) in maximum length, without either lifting plug, fuze, or casting funnel. It has a maximum diameter at the rotating band of 15.80 centimeters (6.22 inches) and an average overall projectile weight of 45.8 kilograms (101.0 pounds). The projectile contains 11.0 kilograms (23.5 pounds) of type 1 TNT (MIL-T-248).

Test Arrangements

Each test layout consisted of one donor and two acceptor projectiles arrayed in a straight line and raised off the ground

to simulate the conveyor system's average height above the building floor as shown in figure 2. The center specimen served as the donor while the projectiles at either side served as the acceptor specimens, thus producing two acceptor sets of test data results for each test donor detonated. During the exploratory test phase, the test separation distance between the donor and the acceptor projectiles was varied, from test to test, and also within single test firings. However, the donor-to-acceptor separation distance was always held constant during the confirmatory test phase.

The exploratory phase of the program consisted of a test array of three 155mm M795 HE Projectiles arranged in a vertical (nose up), linear position, and mounted on a 2.54- by 15.24-centimeter (1.0- by 6.0-inch) pine board to simulate the conveyor system. The test projectiles were supported by low density concrete blocks (two under each donor and acceptor projectile) approximately 45.7 centimeters (18 inches) above the existing terrain to again fully simulate the LAP facility's conveyor system. During this phase, which consisted of 10 test detonations, the separation distances, measured centerline to centerline between the projectiles, ranged from 2.44 to 4.57 meters (8.0 to 15.0 feet).

The confirmatory test phase consisted of a series of 25 tests utilizing the identical test array as that used in the exploratory phase. The centerline separation distances were, however, held constant to compile the necessary statistical data.

Figure 3 is a pre-test view of the projectile array for a typical exploratory test detonation. The left and right acceptors were color-coded to facilitate post-test fragment identification.

Method of Initiation

The donor projectile (detonated sample) was primed with a booster charge consisting of 0.09 kilogram (3.0 ounces) of Composition C4 explosive, had a loaded casting funnel placed in its nose, and was initiated electrically by an engineer's special J2 blasting cap. This method of donor initiation insured that the donor projectile always detonated high order.

TEST RESULTS

General

As previously stated, the safe separation distance propagation tests of 155mm M795 HE Projectiles consisted of an exploratory and a confirmatory test phase. The results of these test phases are discussed below and appear in table 1.

Exploratory Phase

A total of ten exploratory tests were conducted utilizing various separation distances (measured between projectile centerlines), ranging from 2.44 to 4.57 meters (8.0 to 15.0 feet). High order propagations of the donor detonation occurred up to the 3.05-meter (10.0-foot) spacing between projectiles. Figures 4, 5 and 6 are post-test views of the test results. Specifically, the test results in figure 4 were attained with a donor-to-acceptor distance of 2.44 meters (8.0 feet). Note that the projectile body in the picture was severely damaged by donor fragments, but the explosive compositions were not consumed. The thinner metal components in the foreground are recovered casting funnel parts. Figure 5 is a close-up of a deep penetration into an acceptor projectile by a donor fragment at the 3.05-meter (10.0-foot) spacing between the donor and acceptor. This particular acceptor did not detonate from the fragment penetration; it was asserted that this type of damage would eventually lead to the propagation of a projectile. Therefore, a safe spacing of 4.57 meters (15.0 feet) was established for use throughout the confirmatory test phase. Figure 6 is a typical post-test view of an intact acceptor projectile at the 4.57-meter (15.0-foot) spacing. Note that there were fragment hits, but no significant penetrations through the casing of the projectile.

Confirmatory Phase

The confirmatory test phase consisted of 25 test detonations involving 50 acceptors (tests nos. 11 to 35 of table 1) and yielding 50 valid data points at a projectile spacing of 4.57 meters (15.0 feet).

Analysis of Test Results

Variation in manufacturing tolerances, materials, wear, etc., required that statistical methodology be employed when interpreting the confirmatory test data. The actual probability

of the continuous propagation of an unexpected explosive incident at a LAP facility ammunition production line is a function of the number of propagation occurrences in a particular test phase compared to the total number of test detonations conducted (see appendix for statistical theory).

In the confirmatory test phase of the 155mm M795 HE Projectile non-propagation study, a total of 50 observations were recorded at the 4.57-meter (15.0-foot) spacing distance. An upper limit of 7.11 percent probability of propagation of an explosive incident at the 95 percent confidence level has been calculated, using these aforementioned parameters.

Similarly, in a large number of tests, 95 out of every 100 times, the probability of an unexpected explosive incident propagating to a catastrophic event will be less than, or equal to, 7.11 percent. This value is an indication of the quality of the test results and the reliance that can be placed upon the conclusions drawn from the data.

CONCLUSIONS

It may be concluded from the results of the 155mm M795 HE Projectile non-propagation tests that the safe separation distance between adjacent single projectiles with loaded casting funnels is 4.57 meters (15.0 feet). At this distance, the probability of the propagation of an explosive incident is 7.11 percent at the 95 percent confidence level.

Table 1. 155mm M795 HE Projectile single-round tests

Test No.	Separation m	(ft)	Remarks
1L	4.57	(15)	NDP[a], minor hits
R	3.05	(10)	NDP, few funnel penetrations
2L	2.44	(8)	NDP, funnel fragmented, many projectile penetrations
R	2.44	(8)	NDP, projectile and funnel fragmented
3L	3.05	(10)	NPD, funnel fragmented
R	3.05	(10)	NDP, funnel fragmented
4L	3.05	(10)	NDP, funnel fragmented
R	3.05	(10)	NDP, funnel fragmented
5L	3.05	(10)	NDP, funnel fragmented
R	3.05	(10)	NDP, funnel ripped open, projectile cracked
6L	3.05	(10)	NDP
R	3.05	(10)	NDP, funnel fragmented
7L	3.05	(10)	NDP
R	3.05	(10)	NDP
8L	3.05	(10)	NDP
R	3.05	(10)	NDP
9L	3.05	(10)	NDP
R	3.05	(10)	NDP, funnel fragmented
10L	3.05	(10)	NDP, many projectile penetrations
R	3.05	(10)	HOD[b]
11L	4.57	(15)	NDP
R	4.57	(15)	NDP, funnel fragmented
12L	4.57	(15)	NDP, many projectile hits
R	4.57	(15)	NDP
13L	4.57	(15)	NDP
R	4.57	(15)	NDP

Table 1. 155mm M795 HE Projectile single-round tests (cont'd)

Test No.	Separation m	(ft)	Remarks
14L	4.57	(15)	NDP
R	4.57	(15)	NDP
15L	4.57	(15)	NDP, projectile fragmented
R	4.57	(15)	NDP
16L	4.57	(15)	NPD
R	4.57	(15)	NDP
17L	4.57	(15)	NDP
R	4.57	(15)	NDP
18L	4.57	(15)	NDP, minor funnel hits
R	4.57	(15)	NDP
19L	4.57	(15)	NDP
R	4.57	(15)	NDP, funnel fragmented
20L	4.57	(15)	NDP, projectile and funnel fragmented
R	4.57	(15)	NDP
21L	4.57	(15)	NDP
R	4.57	(15)	NDP
22L	4.57	(15)	NDP
R	4.57	(15)	NDP, few funnel penetrations
23L	4.57	(15)	NDP, many funnel penetrations
R	4.57	(15)	NDP
24L	4.57	(15)	NDP
R	4.57	(15)	NDP, few funnel penetrations
25L	4.57	(15)	NDP, few funnel and projectile penetrations
R	4.57	(15)	NDP, funnel fragmented, several projectile hits
26L	4.57	(15)	NDP
R	4.57	(15)	NDP, funnel fragmented

Table 1. 155mm M795 HE Projectile single-round tests (cont'd)

Test No.	Separation m	(ft)	Remarks
27L	4.57	(15)	NDP
R	4.57	(15)	NDP
28L	4.57	(15)	NDP
R	4.57	(15)	NDP, funnel fragmented, few projectile penetrations
29L	4.57	(15)	NPD, few funnel penetrations
R	4.57	(15)	NDP, funnel fragmented
30L	4.57	(15)	NDP, few funnel penetrations
R	4.57	(15)	NDP, few funnel penetrations
31L	4.57	(15)	NDP
R	4.57	(15)	NDP
32L	4.57	(15)	NDP, funnel fragmented
R	4.57	(15)	NDP, funnel fragmented
33L	4.57	(15)	NDP, funnel fragmented
R	4.57	(15)	NDP, few funnel penetrations
34L	4.57	(15)	NDP
R	4.57	(15)	NDP
35L	4.57	(15)	NDP, funnel fragmented
R	4.57	(15)	NDP, funnel fragmented

[a]NDP: No Detonation Propagation

[b]HOD: Propagation to High Order Detonation

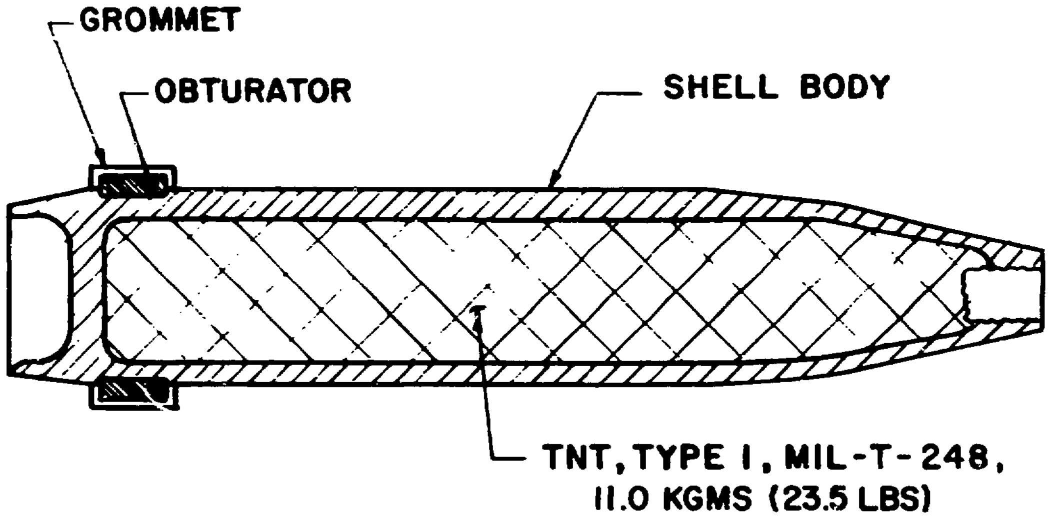

Figure 1. 155mm M795 HE Projectile, cross-section view

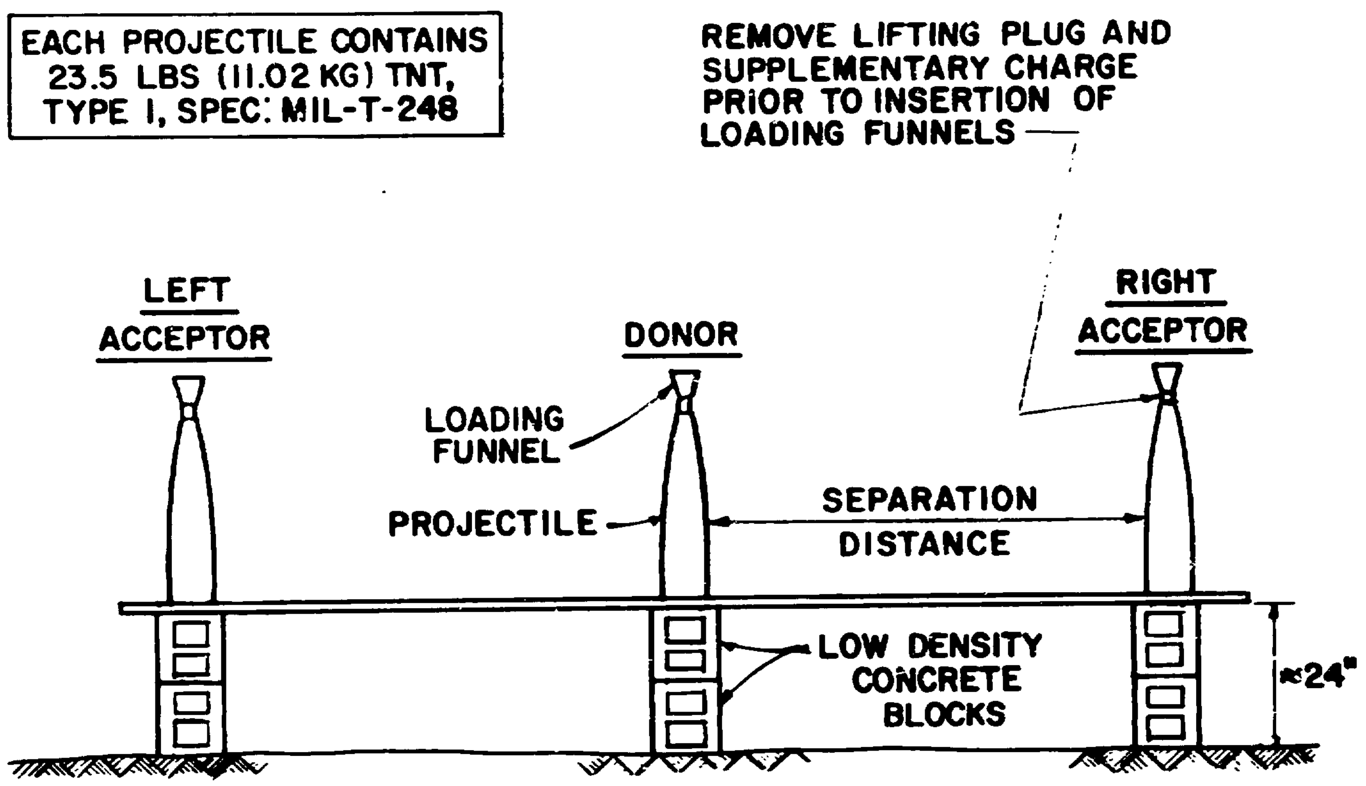

Figure 2. Test schematic

Figure 3. Non-propagation test array

Figure 4. 2.44-meter (8.0-foot) test result

Figure 5. Fragment penetration close-up

Figure 6. 4.57-meter (15.0-foot) test result

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \tag{1}$$

and, therefore, the expected value of (x) is given by

$$E(x) = np \tag{2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \tag{3}$$

where $$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \tag{4}$$

Use of equation 3 is illustrated in the following example:

<u>Example</u>

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based upon 30 observations without a reaction occurrence.

Given

Number of Observations $(n) = 30$
Confidence Level $(\alpha) = 95\%$

Solution

1. Substitute the given value of (α) into equation 4 and solve for ε:

   $\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$

2. Substitute the given value of (n) and value of (ε) into equation 3 and solve for p_2:

   $\varepsilon = 0.025 = (1 - p_2)^{30}$

   or

   $p_2 = 0.116(11.6\%)$

Conclusions

For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of $(0.116 \times 30) = 3.48$ observations could result in a reaction for a 95% confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99%, are used to derive the probabilities. The same values are plotted in Figure A-1.

Table A-1. Probabilities of propagation for various confidence limits

Number of observations	90%	C.L.	95%	C.L.	99%	C.L.
n	p_2	E(x)	p_2	E(x)	p_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

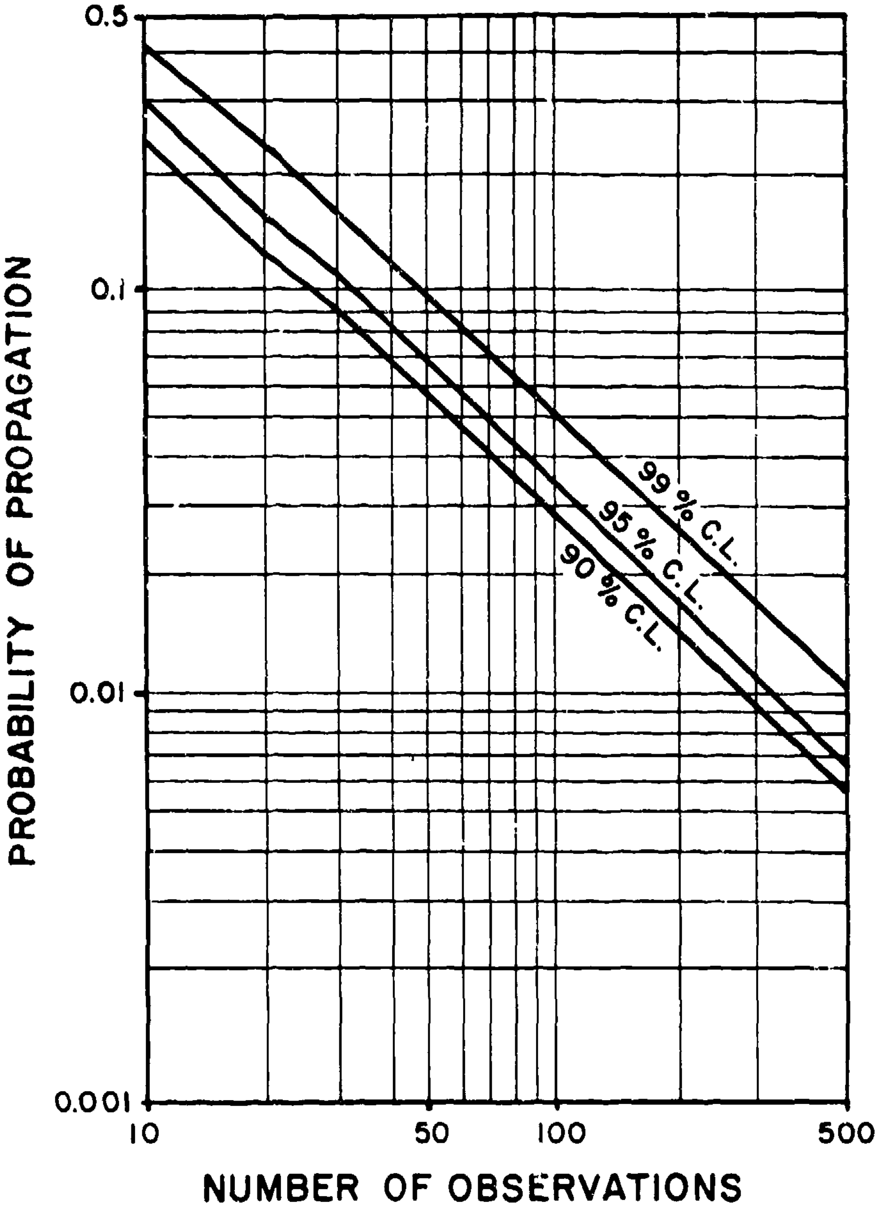

Figure A-1. Variation of propagation probability vs. number of observations as a function of confidence level

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